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PIONEER III AND IV
SPACE PROBES

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PIONEER III AND IV SPACE PROBES*

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Dan Schneiderman

ABSTRACT

A description of the over-all objectives of the Pioneer III and IV experiments is presented. Included is an analysis of the payload design philosophy, a description of the flight hardware, and a synopsis of the results of the experiments.

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I. INTRODUCTION

Early in 1958 the Army Ballistic Missile Agency and the Jet Propulsion Laboratory were asked to prepare a space probe for National Aeronautics and Space Administration as part of the United States' participation in the International Geophysical Year. It was the responsibility of ABMA to provide the booster and guidance sections; JPL was asked to prepare the high-speed propulsion stages, the payload, and its associated ground tracking and telemetering equipment. This combined effort resulted in the successful launching of Pioneer III on December 6, 1958, and Pioneer IV on March 3, 1959 (Fig. 1).

A description of the design considerations and mechanization of the Pioneer III and IV space probes will be given. Pioneers III and IV were nearly identical in design; however, certain detailed differences in mechanization did appear as improvements on Pioneer IV.

The prime objectives of the Pioneer space probe experiments were:

1. To establish a trajectory in the vicinity of the moon
2. To make a significant scientific measurement
3. To advance space technology

Specific design of the payload was subject to several important engineering constraints. Payload weight was limited to 15 lb by the available vehicle and the required trajectory. The mechanical environment (up to 85-g linear acceleration, 600-rpm rotation, and severe shock and vibration) during launching of the high-speed stages imposed severe structural requirements. Thermal balance considerations during the coast period of the trajectory required accurate surface emissivity control.

Because of the weight limitations and the accuracy with which the trajectory was to be established, it was decided that the mission could best be satisfied by a spin-stabilized payload. The stringent weight requirement also made it necessary to tailor the structure closely to the over-all electrical and mechanical needs. This optimization exacted a penalty by minimizing the versatility of the unit. To provide a maximum moment of inertia about the spin axis (so that tumbling would not occur), and an acceptable antenna pattern, the payload configuration itself was limited.

Working within these limitations, a payload having the configuration shown in Figs. 2 and 3 was evolved. The payload was a gold-plated, conical-shaped instrument package, housing a small battery-powered radio transmitter, a cosmic-ray experiment with its associated electronic circuitry, and such developmental devices as an optical trigger, a hydraulic timer, and a despin mechanism.

II. COMMUNICATIONS SYSTEM

The communications system employed in the Pioneer III and IV experiments utilized an extremely low power transmitter. Ground reception used advanced phase-lock techniques for narrow-band detection of both the carrier and subcarrier signals.

To aid in tracking and communications over extended ranges (lunar and beyond) an 85-ft-diameter receiving antenna was employed. This tracking and communications system, known as the TRACE system (Ref. 1), is the outgrowth of earlier JPL-developed Microlock techniques. While the TRACE system was especially established for this series of experiments, it now forms the backbone of the NASA Deep Space Tracking Network.

The airborne portion of the communication system incorporated in the Pioneer space probes consisted essentially of three elements: the audio-subcarrier oscillators, of which there were three, assigned RDB channels 1, 2 and 3; the transmitter, which was phase modulated by the three subcarrier oscillators, and radiated approximately 180 mw of power at a frequency of 960.05 mc; and the antenna, which has a maximum lobe gain of 2.5 db over isotropic.

Choice of this operating frequency for the TRACE space communications system was affected by propagation characteristics within the ionosphere and stratosphere and by galactic, circuit, and other noise considerations. The frequency used in Pioneers III and IV constitutes a compromise between the theoretical optimum and practical considerations.

Subcarrier oscillator. The subcarrier voltage-controlled oscillators were transistorized units developed by JPL for previous programs. It was only necessary to repackage them into the highly integrated structure.

Transmitter. The complete transmitter assembly includes a crystal oscillator (40 mc), frequency multipliers, a modulator, and a final power-output-amplifier stage, packaged as shown in Fig. 4. A block diagram of this unit is shown in Fig. 5. It should be noted that all stages are transistorized with the exception of the final amplifier. The only vacuum tube is a subminiature ceramic UHF triode (GE-7077). Silver-plated magnesium is extensively used in the fabrication of the cavities and chassis for this unit.

Antenna. The selection of the space probe antenna was determined by the following criteria: lightness of weight and mechanical rigidity, reliability (simplicity), optimum gain, and antenna pattern. To meet these requirements several antenna configurations were investigated. The final flight configuration chosen, an unsymmetrical dipole, is shown in Fig. 6.

The antenna was constructed from 0.016-in.-thick laminated epoxy cloth which was formed into a conic section having a base diameter of 9-1/4 in. and a height of 12 in. The cone was flashed with sliver and then plated with gold. In effect, the gold-plated cone acted as a ground plane reflector for a 3-in. quarter-wavelength aluminum probe which was mounted on the top of the cone. The epoxy antenna cone also acted as a protective cover for the payload instrumentation.

Because there was some uncertainty in the exact payload orientation in space for a given trajectory, a study was made of the viewing angle between the payload spin axis and a line going from the payload to the observer (Fig. 7). For several reasons this angle (α) can be predicted only with moderate accuracy. Since α is the function of a particular trajectory, it is necessary to have the antenna beamwidth large enough to cover variations between trajectories. Since the payload was spin stabilized, perturbing torques applied to the payload in space tend to induce anomalous payload motions. Such torques may arise in separation from the final-stage motor, in despin of the payload, or from unforeseen sources. The flight antenna radiation pattern is shown in Fig. 8.

Battery pack. The battery pack supplying power to all the electronics of the probe contained eighteen Mallory RM-42R mercury cells. These cells were chosen because of their relatively high watt-hr/lb output, good regulation, and high reliability characteristics. The batteries were arranged in a ring around the base of the payload structure (Fig. 6) in order to provide the maximum possible moment of inertia about the payload axis. In order to allow extensive testing of the payload with a representative flight-battery source, it was necessary to arrange the battery pack as a replaceable assembly so that a fresh battery pack could be installed just prior to launch. Electrically, the batteries were arranged in three groups of six batteries, eacn group providing a nominal 7.2-volt output. Power for the scaler circuits and transmitter was derived by means of a static converter which produced 17.5 volts and 130-volt B + output. In addition, a regulator circuit was incorporated which provided 6.4 volts for the filament of the final amplifier of the transmitter and 5.5 volts for the dc amplifier circuitry associated with the Anton 213 Geiger tube.

III. OPTICAL TRIGGER EXPERIMENT

Future space missions will involve the photographing of some galactic body. In anticipation of such a need, three devices were included in Pioneers III and IV which could be of later use. The first of these was an optical trigger which could be used to trigger a camera when the probe was in an appropriate position in respect to the moon. The second was a despin mechanism to reduce the angular velocity of the probe to a value compatible with probable photographic exposure times. A third device, a hydraulic timer, was developed to control arming of the trigger mechanism and initiation of the despin operation.

Optical trigger. The optical trigger device was located at the rear of the payload and was exposed to space after the probe was separated from the fourth propulsion stage. This trigger consisted of a lens system, two photoelectric cells, and logic elements which served to create a pulse when an object of sufficient angular size was in the proper part of the field of vision of the trigger mechanism. This device was designed to trigger when the probe passed within an appropriate distance from the moon. The trajectory was chosen to provide an intercept when the lunar surface was properly illuminated. The portion of the moon which would initiate the trigger action was dependent upon the geometry between the payload spin axis, the angle of the trigger in the payload, and the trajectory. This in combination with the arming timer would enable the trigger to operate only after the payload had passed the moon.

For the Pioneer III and IV experiments, the optical trigger device (Fig. 2) was intended to operate as follows. After the probe separated from the fourth stage the optical trigger was exposed and viewed the earth. As the optical trigger scanned the light side of the earth, it generated a pulse alternately switching a bistable multivibrator. The output of the multivibrator was then passed to the channel 1 subcarrier VCO, where it appeared as a square-wave frequency variation of 5 cps magnitude at each earth sighting. However, prior to despin the rotational speed of the probe was too high to permit the system to respond to this switching rate and the output settled out at an intermediate frequency. Shortly after separation the hydraulic timer actuated the despin mechanism which slowed the probe's rotational speed to approximately 5 rpm. A memory circuit which was part of the optical trigger mechanism was not armed until the probe was in flight about 18 hr. At this time if the probe was on trajectory, the earth would subtend an angle to the probe which would not be sufficiently large to stimulate the optical trigger. As an indication that the trigger had been activated by the moon, the trigger's memory circuit shifted the output frequency of the VCO by a discrete increment upon first sighting after arming. Each alternate sighting of the moon would then be indicated by a square-wave output generated around the newly established baseline.

Despin mechanism. As mentioned previously, a payload despin technique was required to accommodate a possible future photographic mission by a spin-stabilized payload. For this purpose the final spin rate must be low (about 5 rpm) but greater than zero. A zero spin rate would fail to provide spin stabilization of the space instrument. It would also fail to guarantee detection of the moon during the time of intercept, since the detector might be facing away from the moon.

The initial high spin rate was necessitated by the need to stabilize the high-speed stages of the Juno II vehicle. Consideration of techniques to provide an initial spin rate for the payload lower than the spin rates of the stages upon which it rested were abandoned in favor of techniques that reduced the spin rate in flight.

The probe was revolving at approximately 600 rpm at the time of its separation from stage 4. It was to continue to revolve at this speed for approximately 10 hr. Upon activation of the despin release assembly by the hydraulic timer, the despin mechanism slowed the probe revolution rate in less than 1/4 sec to 1% of the spin rate that existed just prior to despinning.

The despin mechanism (Fig. 6) consisted of two 6-g counterweights on 60-in.-long nichrome wires. Each wire was attached to the payload by an eyelet which pivoted on a hook mounted on the center-of-gravity plane of the probe, 180-deg opposed. In their preflight position, the counterweight wires were wrapped around the probe and the counterweights were locked into their static position by a pin. Upon activation of the release assembly the counterweights swung out, unwrapping the wires. In the early stages of despinning, the wires were tangentially suspended, and as the probe spin rate decreased to that desired, the wire positions progressed from tangential to radial. In the final stage, the wires reached a radial position which caused the eyelets to pivot off the hooks, releasing the wire-counterweight assemblies to fly off into space carrying with them most of the rotational kinetic energy originally stored in the payload.

The despin release assembly on Pioneer IV was actuated by the firing of an explosive device which received its firing signal from the hydraulic timer switch closure. The firing current was provided by a separate 4-volt battery pack.

Hydraulic timer. To meet the requirements of the initiating operation of the despin and optical trigger experiments at some predetermined time after launch, a timer was required. Studies revealed that this switching could most reliably be accomplished by a hydraulic timer (Fig. 2). The key to the reliability of this unit is its simplicity of operation and design. The timer operated as a closed hydraulic system. A spring-loaded plunger forced a column of silicone fluid through a capillary tube 30 in. long. The flow rate of the fluid through the system controlled the rate of motion of the plunger. The spacing of the spring-loaded switches along the plunger shaft controlled the interval and sequence.

The timer was designed to be started 3.5 hr before launch, to electrically release the despin mechanism 13.5 hr later, and after 21.5 hr of running time, to arm the optical trigger.

IV. TEMPERATURE CONTROL

Temperature control (Fig. 6) of Pioneers III and IV was achieved by controlling the absorptivity and emissivity ratio of the surface of the payload. Since solar heat input would change as a function of the angle between the probe axis and the probe-sun line, which in turn depends on the trajectory used and firing date, it was necessary to have readily controllable average surface characteristics. This was accomplished by having a basic gold-plated surface with overlaid black or white paint strip pattern as required.

V. RADIATION EXPERIMENT

The scientific aspects of the radiation experiment (Fig. 2) were determined by Dr. James A. Van Allen of the State University of Iowa, who also participated in the design and calibration of this portion of the payload. This experiment (Fig. 6) employed two Geiger-Mueller tubes, the first an Anton type 302 tube, whose output was counted by a seventeen-stage binary scaler. This length of counter was chosen to prevent high-count information from being severely attenuated by the narrow bandwidth of communications system. In order to cover the extreme dynamic ranges expected in counting rates within the design bandwidth of the communications system, a unique data processing scheme was employed. By passing the outputs of the ninth, thirteenth, and seventeenth stages of the scaler through suitable weighting networks and then linearly combining them to give different peak-to-peak amplitudes, an output as is shown in Fig. 9 was achieved.

A second Geiger-Mueller tube, Anton type 213, served two different purposes on Pioneers III and IV. On Pioneer III its function was to provide coverage in the high-intensity region of radiation. On Pioneer IV, it was shielded by a 4-g/cm^2 lead shield, and its function was to provide a degree of discrimination against lower-energy particles. This was an attempt to determine the nature and the quantity of the particles. In operation, the pulses obtained from the Anton type 213 tube were integrated in a low-pass filter and the average voltage thus formed was fed to the channel 2 subcarrier oscillator through a unity-voltage-gain power amplifier.

The Geiger tubes encased in their flight containers and the scaling circuits are shown in Fig. 6. In the center of the scaling circuitry is a cylinder containing a potted high-voltage power supply which also served to mount the Geiger tubes. The small cylinder mounted on the center of this power supply is the voltage reference tube for the high-voltage system.

VI. RESULTS

Pioneer III did not achieve escape velocity. However, it reached an altitude of 63, 500 mi from the earth and obtained some very valuable radiation data during its flight of 38 hr and 6 min. Pioneer III was tracked as it re-entered the earth's atmosphere, at a speed in excess of 23, 000 mph, where it burned up from aerodynamic heating at an estimated altitude of 55 mi above the earth, at 19:51 GMT on December 7, 1958.

Pioneer IV came within 37, 300 mi of the moon 41 hr after launch. The probe's transmitter continually radiated an intelligible signal for 82 hr and 6 min before its batteries were depleted. At the time of the batteries' exhaustion the probe was more than 407, 000 mi from the earth and being tracked by the 85-ft dish of the JPL Goldstone tracking station. Pioneer IV is now in a heliocentric orbit having a perihelion of 91. 7 million miles, an aphelion of 106. 1 million miles, a period of 394. 75 days, and an infinite orbital life.

Telemetry data from Pioneer IV indicated that 11 hr and 20 min after launch the payload's rotational speed was reduced from 420 to 11 rpm, indicating action of the despin mechanism.

The light sensor which was to have been triggered by reflected light from the moon was not triggered since it was designed to work at a maximum range of 20, 000 mi.

After launch, as the payload moved out of the shadow of the earth, the temperature very rapidly reached its steady-state value. For Pioneer III, the value so obtained was 38°C, and for Pioneer IV the value was 42°C. The results of these measurements not only verified the payload thermal design but also demonstrated the adequacy of the measurements used to determine radiative properties of the materials involved.

The measurement of high-intensity radiation carried out with the Explorer satellites and Pioneers III and IV was under the direction of Dr. Van Allen. Analyses of the results of these measurements have been made by Dr. Van Allen and his associates and have been reported to the U. S. National Committee for the IGY. (Refs. 2, 3, 4)

At altitudes below about 1000 km, the radiation measurements indicated a cosmic-ray intensity which agreed with extrapolations made on the basis of experiments with high-altitude rockets and balloons. However, using Explorer satellite data above 1000 km a sudden anomalous increase in cosmic-ray activity was noted.

These observations, begun with the Explorer satellites, were projected to extreme altitudes by the measurements taken on board Pioneers III and IV. A diagram of the probable shape of these two belts is shown in Fig. 10. This diagram shows the trajectory of Pioneer III plotted in geomagnetic coordinates. Counting rates at distinct points along the trajectory are indicated by the contour lines drawn through those points. At low altitudes, these contour lines coincide with those discovered by the Explorer satellites. At high altitudes the contour lines are drawn to reasonably fit the data obtained from Pioneer III. The contour lines in regions not actually traversed by this probe are speculative but are drawn consistent with both the Explorer and Pioneer III data.

Although the peak intensity of both radiation belts encountered by Pioneer IV appears to occur at the same altitudes as those encountered by Pioneer III, the extension of the belt beyond this maximum is quite different for these two probes. For Pioneer III the belt appears to end at an altitude of approximately 60, 000 km following a steady decrease in counting rate to an apparent asymtotic value. Beyond that, the counting rate is very nearly constant. For Pioneer IV quite different results were obtained. Not only does the belt appear to extend to much greater altitudes, apparently not terminating until an altitude of about 91, 000 km is reached, but furthermore, as the edge of the belt is approached the decrease of radiation is not at all steady. The data taken during the remaining flight of Pioneer IV from the limit at which radio signals were received (66, 000 km) to the apparent limit of the radiation belt (91, 000 km) show only minor fluctuations which appear to be within the expectations of statistics.

It must be remembered that the nature and structure of the radiation zones, as represented by the data so far obtained, depend critically upon the nature of the detectors used in the probes. Different detectors sensitive to different energies and types of radiation might give quite different results. A complete picture of radiation activity above the earth's atmosphere can be constructed only when much more detailed observations have been made with additional rocket flights into this most interesting region.

Although all detailed objectives were not achieved, Pioneers III and IV provided much useful scientific and technological information, specifically in the measurement of the Van Allen radiation belts and in the development of advanced communications techniques. Indeed, the lessons learned in the design of the United States' first space vehicle have proven invaluable in the preparation of the next generation of spacecraft.

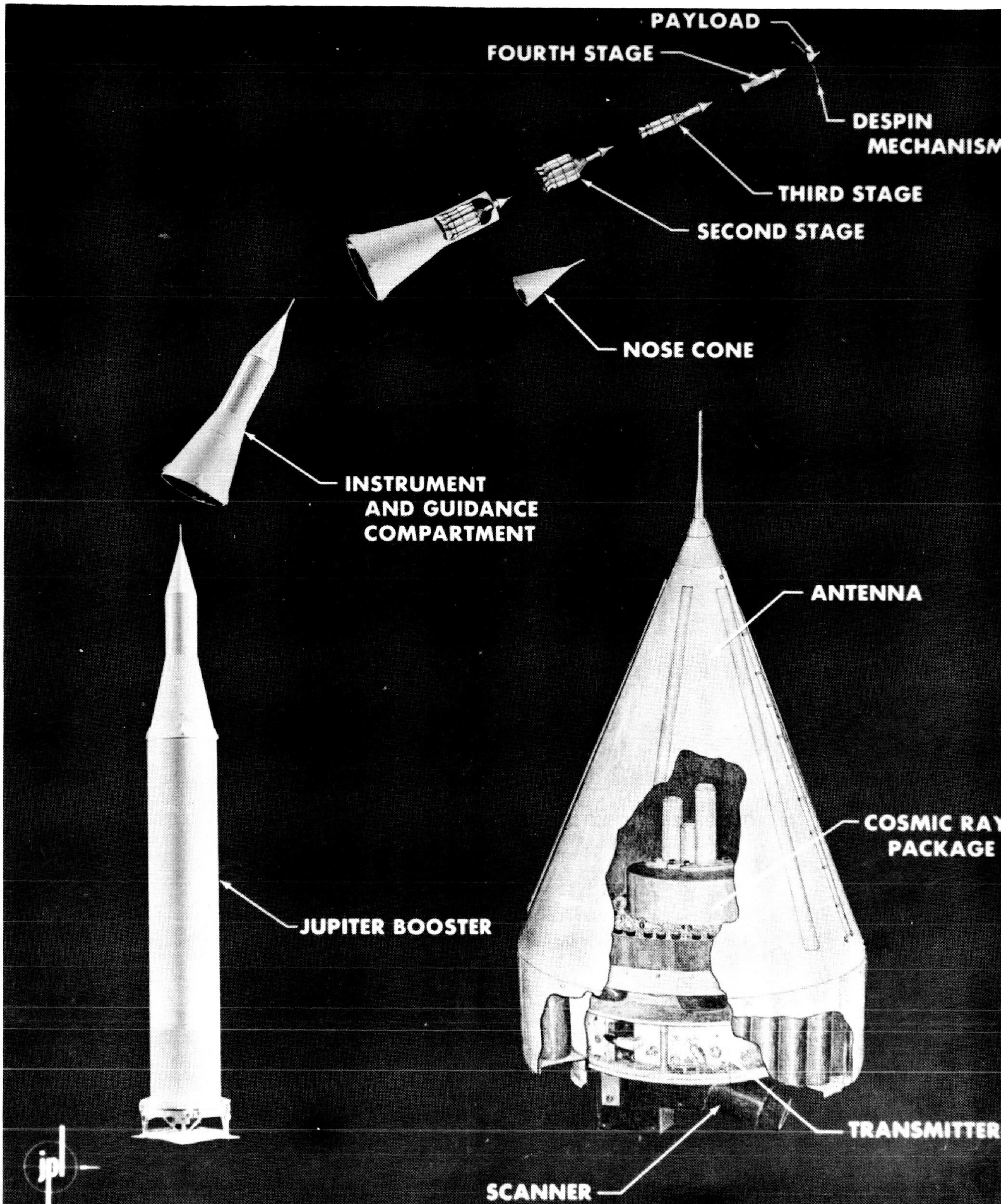

Fig. 1. Pioneer III

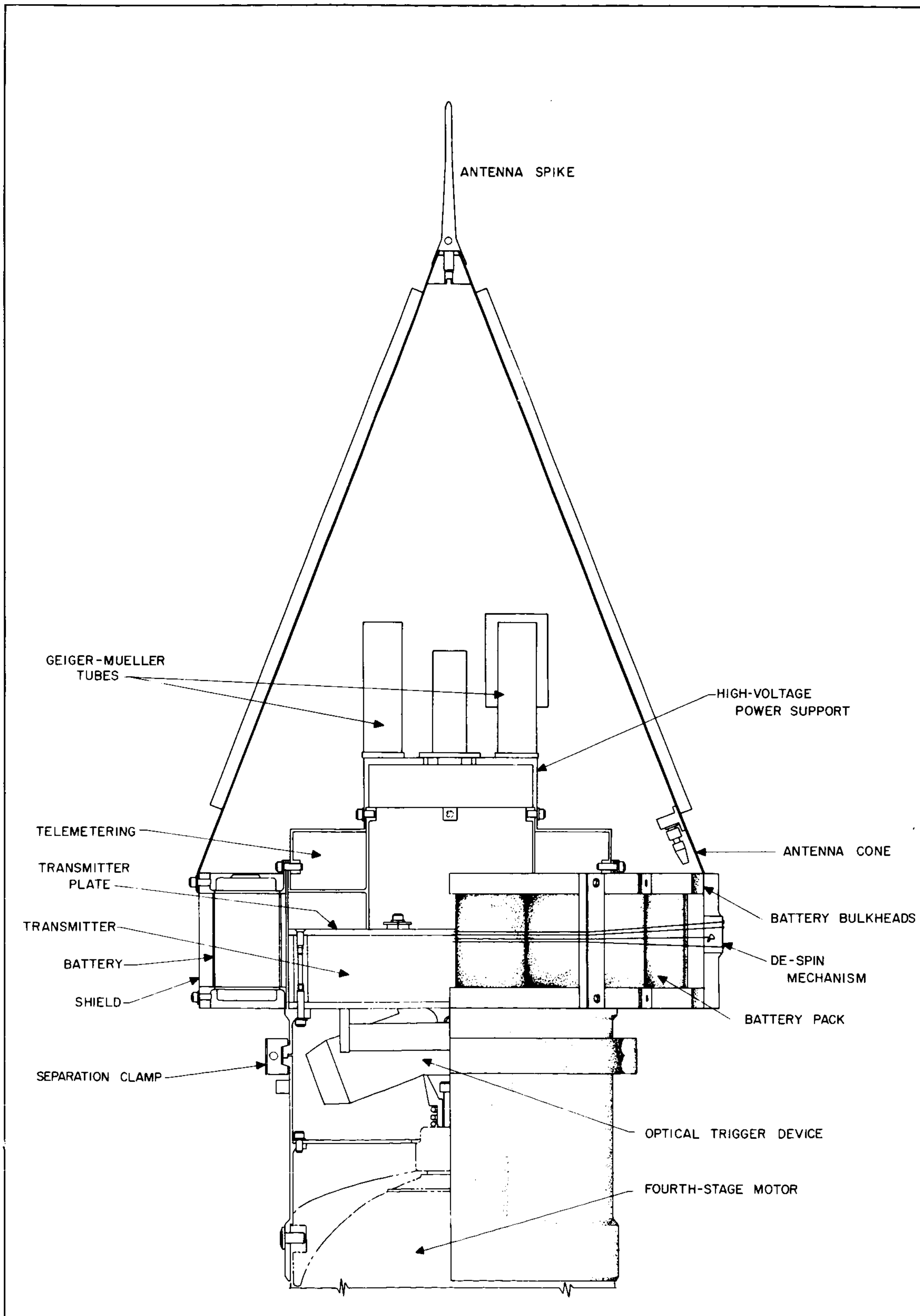

Fig. 2. Pioneer IV

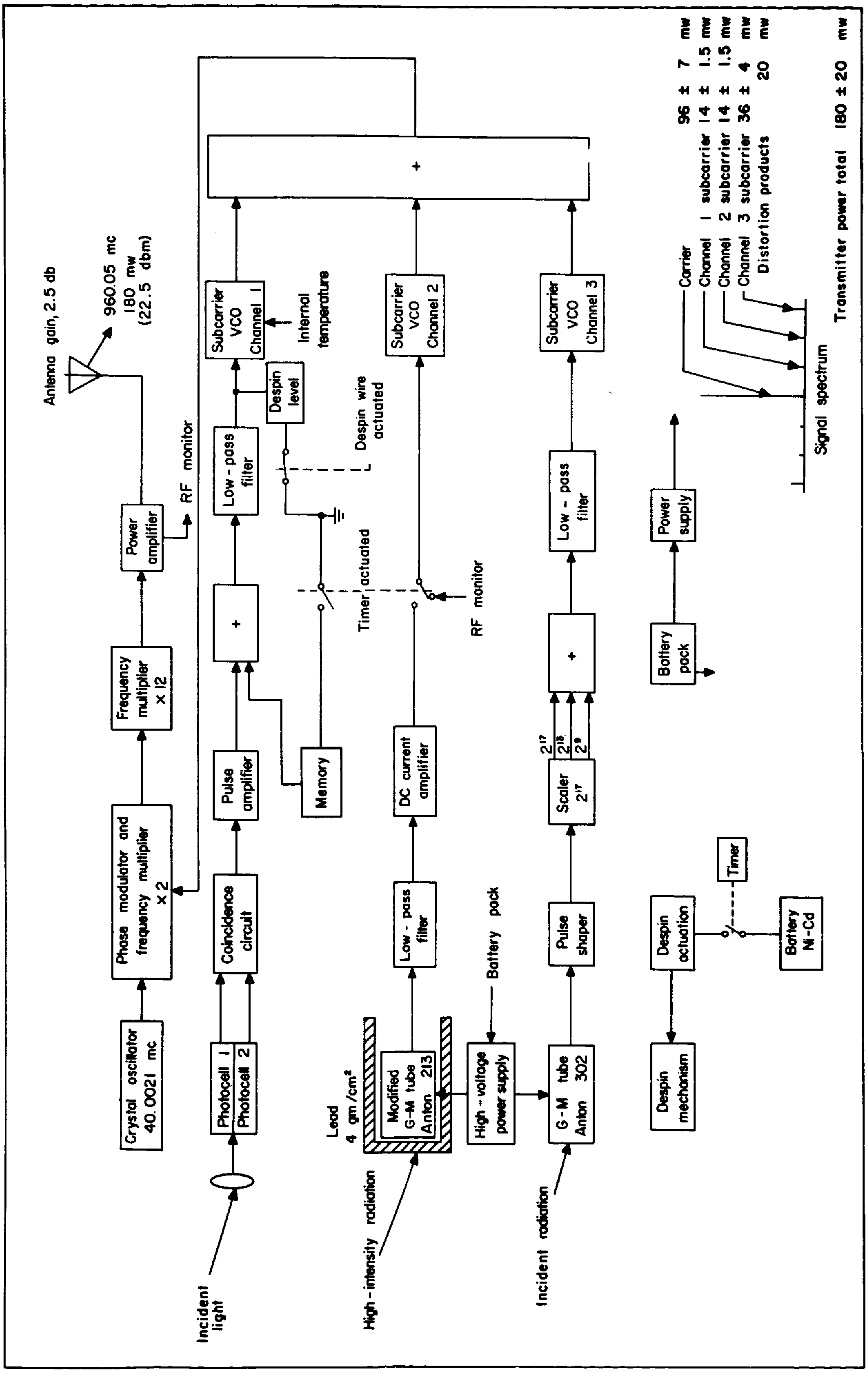

Fig. 3. Block Diagram of Pioneer IV

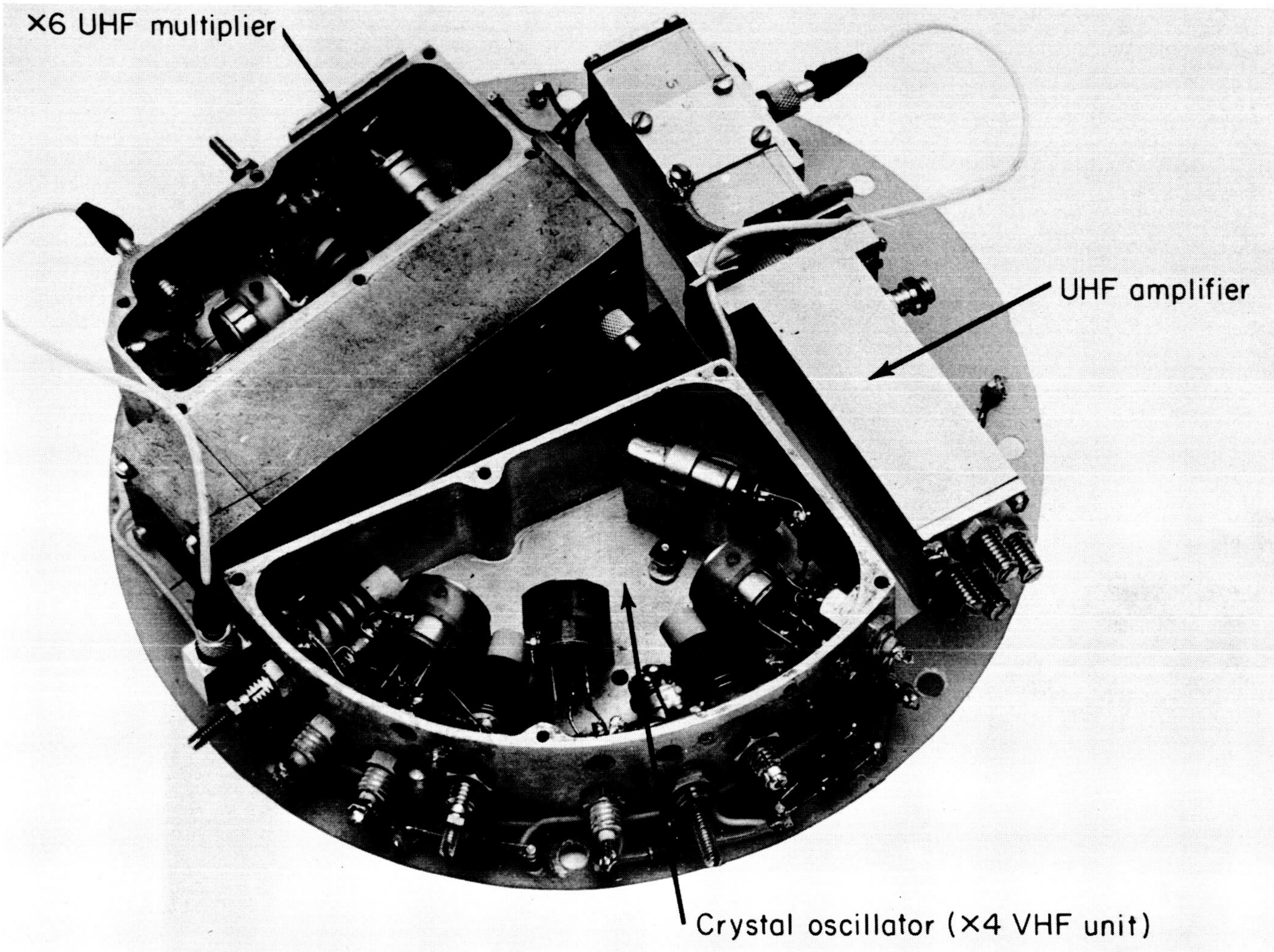

Fig. 4. Pioneer IV Transmitter

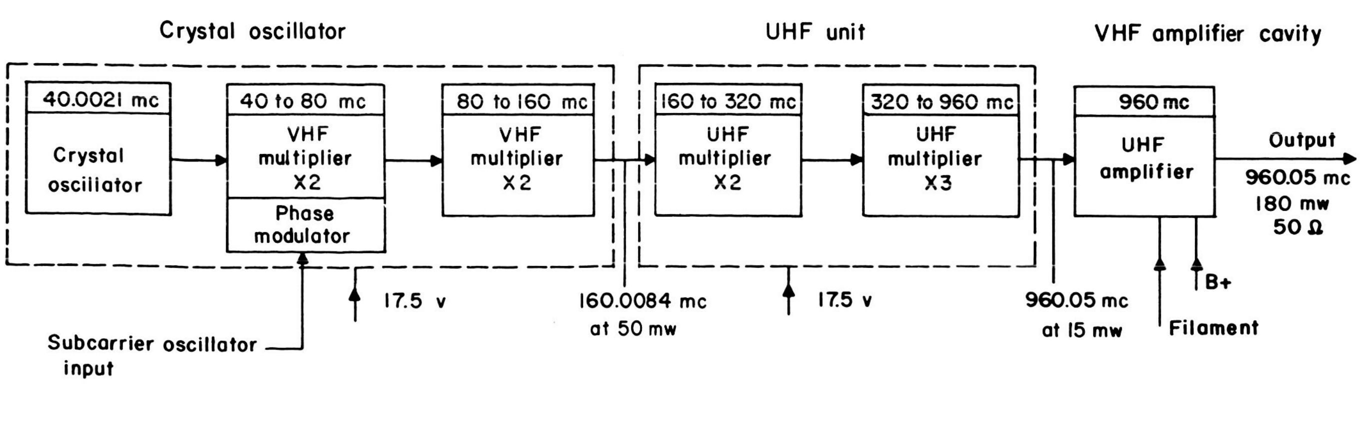

Fig. 5. Block Diagram of Transmitter

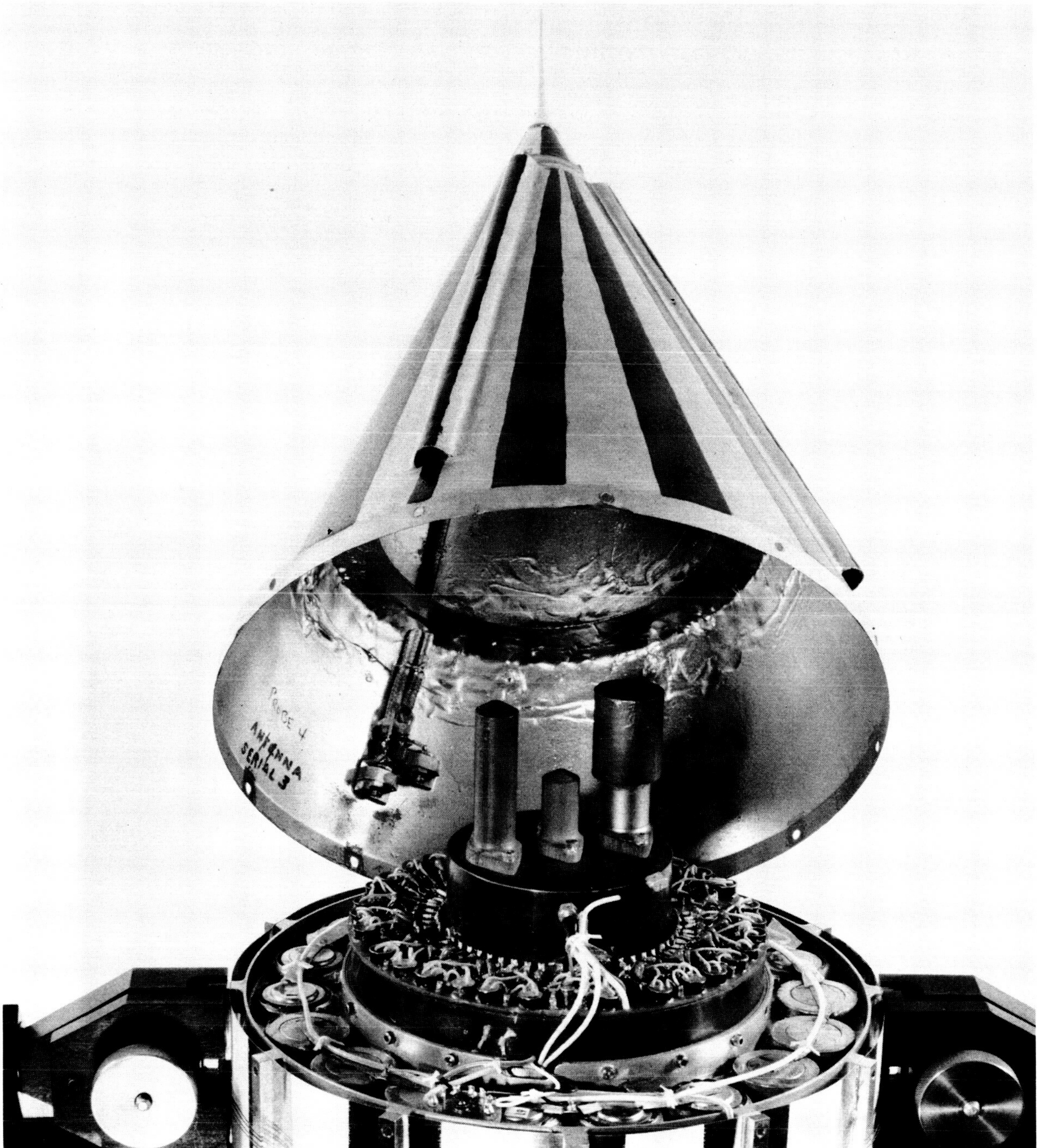

Fig. 6. Internal View of Pioneer IV

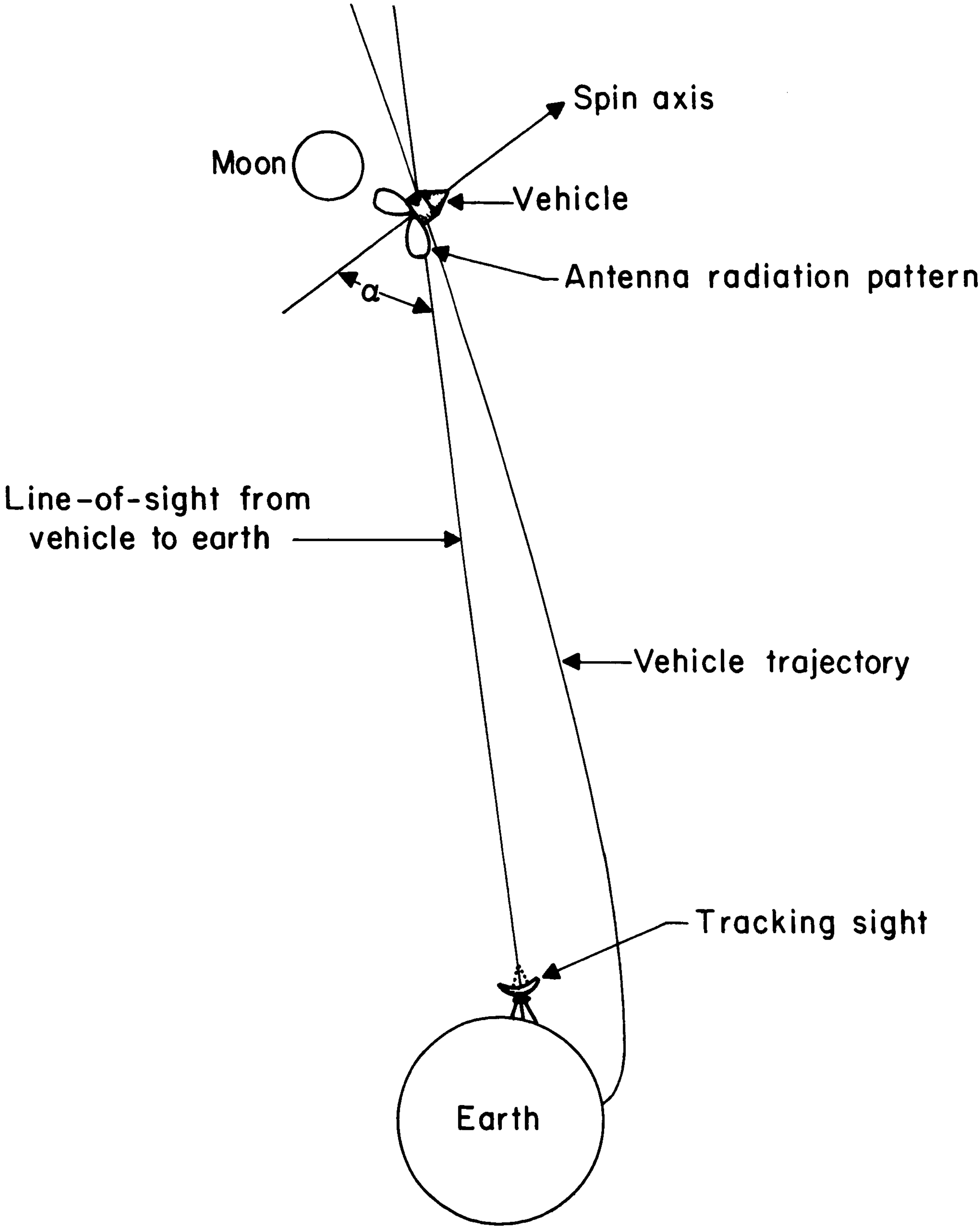

Fig. 7. Antenna Look Angle

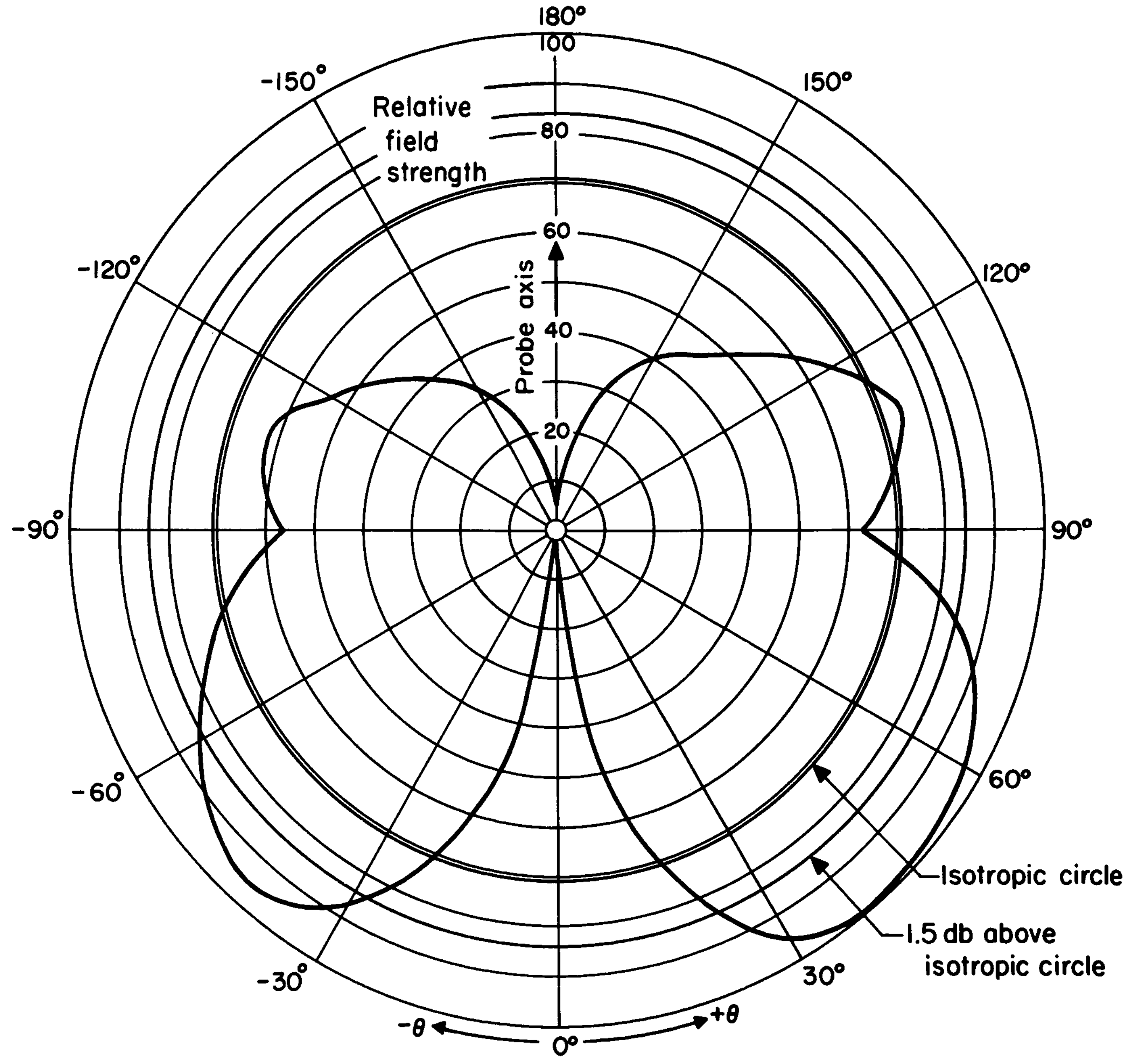

Fig. 8. Pioneer IV Antenna Pattern

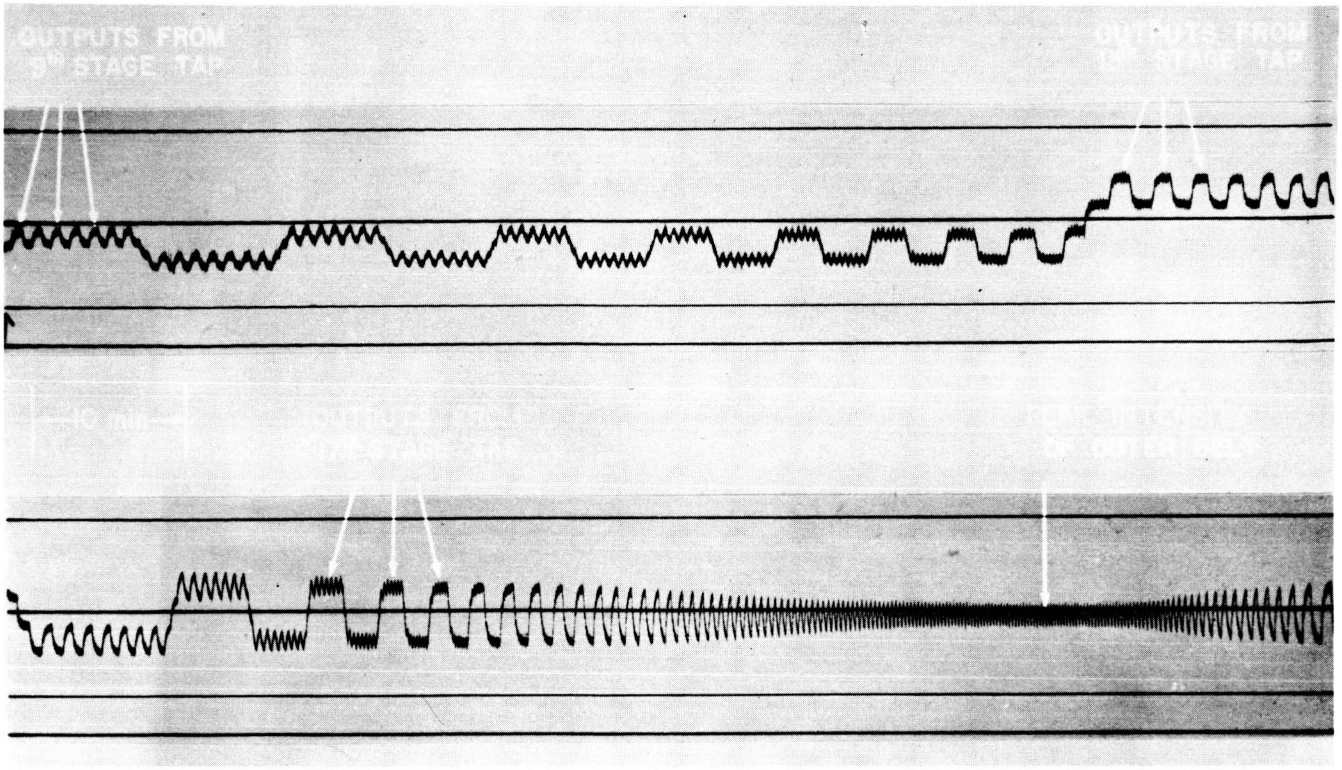

Fig. 9. Pioneer III Radiation Data as Monitored at Puerto Rico

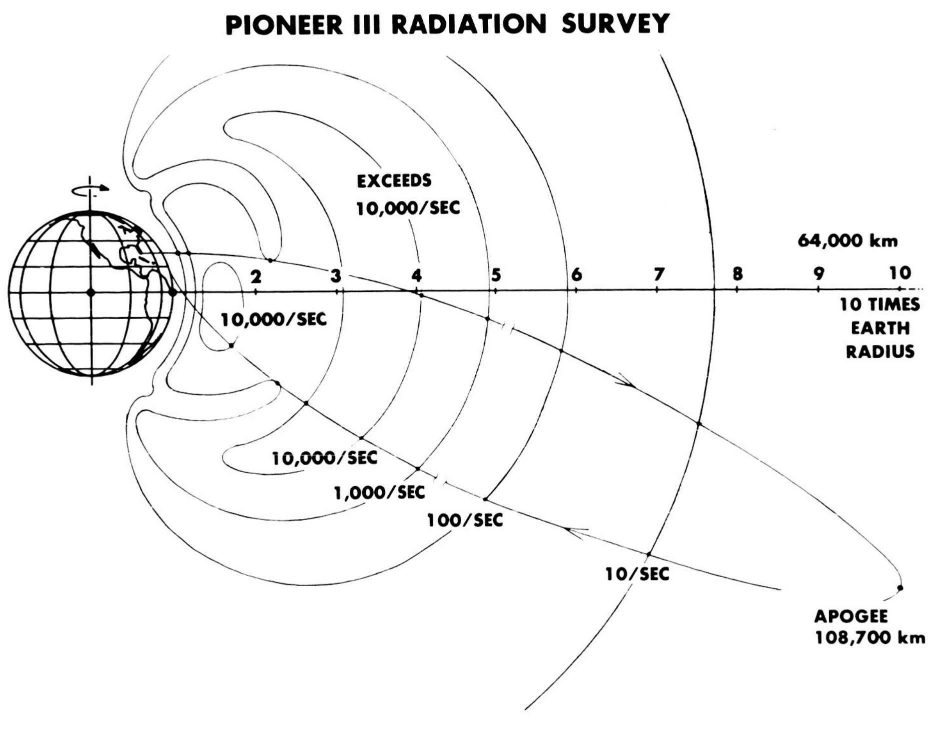

Fig. 10. Van Allen Radiation Belts

REFERENCES

1. Brockman, M. H., Buchanan, H. R., Choate, R. L., Malling, L. R., Extra-Terrestrial Radio Tracking and Communication, (to be printed in February 1960 issue of IRE).

2. Van Allen, J. A., Ludwig, G. H., Ray, E. C., and McIlwain, C. E., Observation of High Intensity Radiation by Satellites 1958 Alpha and Gamma, State University of Iowa, Iowa City, May 1, 1958.

3. Van Allen, J. A., Ludwig, G. H., and McIlwain, C. E., Radiation Observations with Satellite 1958 Epsilon, State University of Iowa, Iowa City.

4. Van Allen, J. A., Frank, L. A., Survey of Radiation Around the Earth to a Radial Distance of 107,400 Kilometers, State University of Iowa, Iowa City, January 1959.